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Stress distribution in a pin-loaded  
plate with glued reinforcement plates.

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STRESS DISTRIBUTION IN A PIN-LOADED  
METAL PLATE WITH GLUED REINFORCEMENT PLATES

A Thesis  
Submitted to the Graduate Faculty  
of the  
University of Minnesota

by  
Robert C. Morris

In Partial Fulfillment of the Requirements  
for the  
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page 2

## PREFACE

Following World War II, the advent of the use of sandwich materials in the construction of aircraft presented many new problems to industry. The importance of this material was firmly established by the time Chance Vought Aircraft built the U.S. Navy model F7U airplane. This aircraft, a carrier based, jet propelled fighter, is the first American production model to feature the use of sandwich skin.

In spite of this, however, sandwich design theories are not as fully developed as those involving the use of more "conventional" materials. Therefore, Chance Vought was able, on being approached by the student, to suggest the problem that was investigated for this thesis. In addition, they very kindly supplied the glued panels from which the test specimens were made.

This thesis, then, presents the results of the study, which was carried out during the 1951-52 school year at the University of Minnesota, Minneapolis, Minnesota.





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## SUMMARY

This thesis presents the results of an investigation of one theory concerning the stress distribution in a pin-loaded metal plate with glued reinforcement plates. The theory itself was developed as an aid in finding shear stresses in the glue.

Five aluminum plates of the type used in aircraft construction, were tested in tension. Each plate was loaded at one end by a uniform load, and near the other end by a one inch diameter pin. The location of the pin was the variable from plate to plate.

The results indicated that the proposed theory was not suitable, because the loading for which the theory was developed was sufficiently different from the actual loading conditions.

Wide variations in strains produced by hole and pin combinations that were apparently the same, indicate that it may not be accurate to assume that pin or bolt bearing is truly uniform. Though this is a by-product of the present investigation, it is felt that further study along these lines is warranted.



## INTRODUCTION

This research was suggested by the requirements resulting from the use of sandwich material in the construction of the newer military aircraft. The test specimens used were not sandwich materials, however, and the following is presented in order to explain the choice of test materials, and the applicability of the results to the design of fittings and attachments for sandwich materials.

The usual design of a sandwich panel to which bolts or rivets are attached involves the use of a hardwood insert and bonded metal doublers. The insert supplies resistance to transverse shear and crushing forces, and the doublers increase bearing strength. An example of one type of fitting is illustrated as Figure 1. An applied load transfers from the bolt or rivet to the doublers and the sandwich facings. The facings must take all of the load beyond the doublers, and the portion of the load that is introduced into the doublers must be transferred through the adhesive into the facings.

The strength of the fitting attachment depends upon the strength of the bond between the facing and the doubler. Thus, it is desirable to know the distribution of stresses within the bonding, in order to compare those stresses with

# CHAPTER

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the shear strength of the adhesive. With this information, it will be possible to make the best use of bonding material and to design attachments most efficiently.

In the design of sandwich parts, the core, whether it is of balsa, or of one of the many other commonly used materials, is considered to offer no tensile strength in a direction parallel to the plane of the facings. Since this investigation was concerned only with those forces, the core could be of no value, and it was possible to treat the problem independently of any actual sandwich panels.

Figure 1 illustrates only one type of fitting that might be attached to a sandwich sheet. Another type, for example, might be an L-shaped bracket. In addition to the tensile forces mentioned above, such a bracket would apply a moment to the sandwich. This problem is no doubt of interest, but it would have complicated the present research beyond its intended scope.

For these reasons, a specimen such as that of Figure 2 was chosen. For the purposes of this analysis, Figure 2 can be treated as structurally the same as Figure 1. They are in fact the same, except that in the latter figure, the balsa core has been removed, and the two face plates have





been placed together to be considered as one. In each case, the load is applied by the pin to the doublers and face plates simultaneously. In each case, the load is finally transmitted from the doublers to the center piece.

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## THEORY

The theory presented in this section was not developed for the specific loading condition pictured in Figure 2. It was, instead, developed for the case of the standard glued lap joint shown in Figure 3(a).

It is assumed that, due to symmetry, the single lap joint of Figure 3(a) could be considered to be essentially the same as the double lap joint of Figure 3(b).

The application of the theory to the test panels will be discussed in the next section.

The following symbols will be used in the theoretical development:

- A, B - constants of integration
- c - a constant
- E - Young's modulus of elasticity
- G - shear modulus of the glue
- L - lap length
- N - total applied load
- $N_1$  - load applied to sheet 1
- $N_2$  - load applied to sheet 2



$P_1$  - force acting at any point,  $x$ , in sheet 1

$P_2$  - force acting at any point,  $x$ , in sheet 2

$t$  - sheet thickness or glue thickness

$u_1$  - displacement of a particle in sheet 1

$u_2$  - displacement of a particle in sheet 2

$\gamma$  - shear strain in the glue

$\sigma$  - normal stress

$\tau$  - shear stress in the glue

The lap joint pictured in Figure 3 is taken as being of unit width perpendicular to the paper. It is further considered to be rigidly supported.

Consider the static equilibrium of an element of sheet 1 next to the glue line.

$$\Sigma F_x = 0$$

$$= -P_1 + P_2 + \left(\frac{dP_1}{dx}\right)dx - \tau dx$$

This gives:

$$\frac{dP_1}{dx} = \tau \tag{1}$$

$$\frac{d^2P_1}{dx^2} = \frac{d\tau}{dx} \tag{2}$$



By definition:

$$\begin{aligned} \gamma &= \frac{\tau}{G} \\ &= \frac{u_1 - u_2}{t_g} \end{aligned}$$

These two equations combine to give:

$$\begin{aligned} \tau &= \frac{G}{t_g} (u_1 - u_2) \\ \frac{d\tau}{dx} &= \frac{G}{t_g} \left( \frac{du_1}{dx} - \frac{du_2}{dx} \right) \end{aligned} \quad (3)$$

Using Hooke's law with (3):

$$\begin{aligned} \frac{d\tau}{dx} &= \frac{G}{Et_g} (\sigma_1 - \sigma_2) \\ &= \frac{G}{Et_g} \left( \frac{P_1}{t_1} - \frac{P_2}{t_2} \right) \\ &= \frac{G}{Et_g} \left[ \frac{P_1}{t_1} - \frac{N - P_1}{t_2} \right] \\ &= \frac{G}{Et_g} \left[ P_1 \left( \frac{1}{t_1} + \frac{1}{t_2} \right) - \frac{N}{t_2} \right] \\ &= \frac{G}{Et_g} \left( \frac{1}{t_1} + \frac{1}{t_2} \right) \left[ P_1 - \frac{N}{t_2 \left( \frac{1}{t_1} + \frac{1}{t_2} \right)} \right] \\ &= \frac{G}{Et_g} \left( \frac{1}{t_1} + \frac{1}{t_2} \right) \left[ P_1 - N \left( \frac{t_1}{t_1 + t_2} \right) \right] \end{aligned} \quad (4)$$





Next define the constant  $c^2$ :

$$c^2 = \frac{G}{\epsilon t_2} \left( \frac{1}{t_1} + \frac{1}{t_2} \right) \quad (5)$$

Substituting (5) into (4) and equating the result with (2) gives:

$$\frac{d^2 p_1}{dx^2} = c^2 p_1 - c^2 \left( \frac{N t_1}{t_1 + t_2} \right)$$

$$\frac{d^2 p_1}{dx^2} - c^2 p_1 + c^2 \left( \frac{N t_1}{t_1 + t_2} \right) = 0 \quad (6)$$

The solution for (6) may be written as:

$$p_1 = N \left( \frac{t_1}{t_1 + t_2} \right) + A \sinh \alpha x + B \cosh \alpha x \quad (7)$$

The boundary conditions are:

$$p_1 \Big|_{x=0} = N \frac{t_1}{t_1 + t_2}$$

$$p_1 \Big|_{x=L} = 0$$

From the boundary conditions, it is seen that

$$B = 0$$

$$A = - \frac{N t_1}{(t_1 + t_2) \sinh \alpha L}$$



So that (7) finally becomes:

$$p_1 = \frac{Nt_1}{t_1 + t_2} \left( 1 - \frac{\sinh cx}{\sinh cL} \right) \quad (8)$$

Before proceeding further, reference should be made to Figure 3. Formula (8) was developed for either of the two lap joints represented in Figure 3(a). The actual case under consideration is not Figure 3(a), but is Figure 3(b) (this statement is not strictly true, and it is discussed in detail in the next section), and in order for (8) to apply to this latter figure, the dimensions of the test specimen must be made to fit its nomenclature. This will be recognized in the next section.

As stated in the introduction, the main interest is in  $\tau$ , and not in  $p_1$ . The quantity  $p_1$  is merely a tool to assist in the investigation of  $\tau$ . From (1) and (8):

$$\tau = - \left( \frac{c N t_1}{t_1 + t_2} \right) \frac{\cosh cx}{\sinh cL} \quad (9)$$

From which:

$$\begin{aligned} \tau_{\max} &= - \left( \frac{c N t_1}{t_1 + t_2} \right) \frac{\cosh cL}{\sinh cL} \\ &= - \left( \frac{c N t_1}{t_1 + t_2} \right) \coth cL \end{aligned} \quad (10)$$



From (10) it is apparent that as  $L \rightarrow 0$ ,  $\tau_{max} \rightarrow \infty$ . This is what might be expected from the realization that as  $L \rightarrow 0$ , there is a diminishing area to resist the applied loads.

Equation (10) is as far as the theoretical analysis need be carried for this work. A discussion of the use to which the theory was put, appears in the next section.



#### PURPOSE OF TESTS

It was felt that the validity of the theoretical analysis might best be demonstrated by tests that would give answers to two questions:

- (a) Does equation (9) give a true representation of the shear stress in the glue?
- (b) Is it correct to assume that in a pin-loaded joint, the loading is uniform along the bolt line? That is, can the actual loading, as shown in Figure 2, be accurately represented by a theoretical analysis of the joint of Figure 3?

In order to study the first question, evaluate  $p_1$  for the actual test panels. If  $p_1$  follows the distribution as given by (8), it may safely be assumed that  $p_1$  will follow the distribution given by (9). Numerical values that are needed are:

$$G = 11 \times 10^4 \text{ pounds per square inch}$$

$$E = 10.3 \times 10^6 \text{ pounds per square inch}$$

$$t_g = 0.005 \text{ inches}$$

$$t_1 = 0.032 \text{ inches}$$

$$t_2 = 0.032 \text{ inches}$$





These values substituted into (5) yield:

$$c = 11.55 \frac{1}{\text{inches}} \quad (11)$$

Using (11) and the above numerical values in (2):

$$P_1 = N \left( \frac{1}{4} - \frac{\sinh 11.55 x}{\sinh 11.55 L} \right) \quad (12)$$

$$= N \left( \frac{1}{4} - \frac{e^{11.55 x} - e^{-11.55 x}}{e^{11.55 L} - e^{-11.55 L}} \right) \quad (13)$$

A negligible error will be introduced if (13) is rewritten as:

$$P_1 = N \left( 0.25 - \frac{e^{11.55 x}}{e^{11.55 L}} \right)$$

Then for a change  $\frac{\Delta P_1}{P_1} \geq 0.10$ , it will be required that:

$$\frac{e^{11.55 x}}{e^{11.55 L}} \geq 0.025$$

But since  $\frac{1}{e^{\theta}} \geq 0.025$  only for  $\theta \leq 3.69$ , this requirement may be stated as

$$11.55 (L - x) \leq 3.69$$

$$x \geq L - 0.32 \text{ inches}$$

Let  $f(x) = x^2 + 1$  and  $g(x) = x^2 - 1$ .

$$\frac{f(x)}{g(x)} = \frac{x^2 + 1}{x^2 - 1}$$

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This indicates that in order to obtain a 10% reduction in  $p_1$  it would be necessary to take measurements of strain at a distance of 0.32 inches from the edge of the doubler. For a greater reduction in  $p_1$ , observations would have been necessary even nearer the edge. Because of the lack of experience in experimental techniques, particularly those involving the proper handling and mounting of electric resistance strain gages, it was not felt that much of value could be obtained from an investigation along these lines. Furthermore, it was believed that any study of this question should be based on the correctness of the assumption (b) above. For unless this assumption were correct, there would be little point in trying to evaluate the accuracy of (8).

For these reasons, all tests were carried out for the purpose of answering (b) above.



## EQUIPMENT

All test specimens were made of 75S-T6 Alclad aluminum alloy. A sample is illustrated in Figure 4 and pictured in Figure 5. They were made by the student from the two 16 x 36 inch glued but undrilled panels furnished by the Chance Vought Division of The United Aircraft Corporation, Dallas, Texas. Doublers were glued at the factory in order to duplicate actual manufacturing conditions.

The nominal thickness of the core was given as 0.064 inches, and the nominal thickness of the doublers was given as 0.032 inches. Measurements at many spots along the edges of each cut test specimen indicated that it varied from 0.065 inches to 0.068 inches for the core, and from 0.032 inches to 0.035 inches for the doublers.

Nominal glue thickness was given as 0.006 to 0.009 inches. A laboratory check in two spots indicated that glue thickness was 0.005 inches. This check was made using the microscope from a Beggs Deformeter set. The instrument was rather crudely calibrated with a Brown and Sharp machinists' scale which was divided into 0.01 inch spaces.

Lap length,  $l$ , as defined in the theoretical development, was assumed to be the distance between the center line



of the loading pin, and the edge of the doubler that was nearest the end of the panel under uniform tension. Five lap lengths were tested: 1.5, 2, 2.5, 3, and 6 inches.

SR-4 electric resistance strain gages were glued on at the University as shown in Figures 4 and 5. For each strain gage shown in Figure 5, there is another strain gage exactly opposite, on the other side of the specimen. The type A-11 strain gage (one inch gage length) was used wherever possible, and the type A-8 gage (one-eighth inch gage length) was used as space limitations dictated. A total of ten gages was used on each side of each plate.

All strain gages were wired into a Twenty Point Switching Unit, and then to a Type L Portable Strain Indicator, which gave direct indications of strain, in units of micro-inches per inch.

Tests were conducted on the 120,000 pound Universal Testing Machine located in the University of Minnesota Experimental Engineering Building. Two views of the specimen in the testing machine are presented as Figures 6 and 7. It can be seen from these pictures (Figure 7 in particular), that the gripping jaws normally used with the Universal Testing Machine were not used for the tests. Because it was understood





that such grips have a tendency to slip, the tee-sections pictured were used to hold the specimen in the machine and transmit the load. All bolts shown were tightened with wrenches while a load of about 1000 pounds was held, in order to insure proper alignment of the tees with the faces that they matched on the machine. Separators kept the lower pulling strap from pressing against the strain gages under it.

The SP-4 strain gages, the Twenty point Switching Unit, the Type L Portable Strain Indicator, and the Universal Testing Machine were all manufactured by the Baldwin-Lima-Hamilton Corporation, Eddystone Division, Southwark Shop, Philadelphia, 42, Pennsylvania.



## PROCEDURE

The laboratory testing procedure consisted of applying loads at 1000 pound intervals, and recording the strains indicated by each gage. As can be seen by Table I, the laboratory data sheet, a load of 100 pounds was considered to be the "zero" load. Increments of 1000 pounds required that the testing machine be loaded to 1100, 2100, 3100 pounds, and so on, up to a maximum of 8100 pounds. This maximum was dictated by the bearing strength at the hole around the loading pin.

Front and back strain gages were read and averaged in order to give the net strain at each point on the specimen.

The only variation from this routine procedure was required when strain gage seven of the six inch lap length plate indicated that part of the plate was in compression instead of the usual tension. The strains were checked by placing Huggenberger Tensometers on each side of the panel, in line with gages 7-10, but  $11\frac{1}{2}$  inches from gages 7-f and 7-b.

Considerable time and effort was spent trying to obtain uniform loading conditions as measured by strain gages 1-3. The results of these efforts did not produce uniform



loading, but they did make the load as uniform as it was felt was possible with the mounting arrangement in use.



## RESULTS AND DISCUSSION

Actual strain indicator readings are given in Tables I(a)-(e). The strains on the front and back of each panel, and their averages, are presented in Tables II(a)-(e). Figures 8-10 are graphical interpretations of the results.

As shown by Figures 8(a)-(e), the strains are not uniform along the bolt line, L, but they increase up to the edge of the hole. The peak loads decrease as the lap length increases from 1.5 to 3 inches, but they increase sharply for a lap length of 6 inches. The latter plate exhibited further unusual characteristics, in that it was in compression along its edges, as shown by Figure 8(e).

There was some doubt as to the accuracy of the electric strain gages at the point of compression, so, in order to check the readings, mechanical strain gages were placed symmetrically opposite them, as explained in the section giving procedures. The mechanical strain gages also indicated compression. There is no way to account for this effect by application of the theory under investigation. The compressive effect was still being felt at the  $\frac{1}{2}L$  line. This is indicated by the fact that the strains at the outer edge of the panel, as given by Figure 9(e), are smaller than those shown





in any of the other curves of Figure 9.

The strain patterns of Figures 9(a)-(e) are similar, with the exception of the curves for the two inch lap length. They were considerably less at any point on this plate than they were on any other plate. This is not explained by equation (8).

The shape of the strain curves along the  $\frac{1}{2}L$  line was assumed to be similar to the shape of the curves showing strain along the bolt line. This, or some other assumption as to shape was necessary due to the limited number of strain gages along this line. As might be expected from Saint-Venant's principle, the strain curves tend to flatten out as the lap length increases, and the  $\frac{1}{2}L$  line is farther removed from the edge of the hole.

The most interesting results are found in an inspection of Figures 10(a)-(e). For convenience make the following definitions:

$P_{lu}$  - the  $p_l$  that would obtain in  
lap joints such as those of  
Figure 3, where loading is uniform

$\epsilon_{lu}, \sigma_{lu}$  - strains and stresses due to  $P_{lu}$



$P_{lact}$  - the actual  $P_l$  determined by  
testing the joint of Figure 2

$\epsilon_{lact}$  - strains resulting from  $P_{lact}$

$\sigma_{lact}$  - stresses resulting from  $P_{lact}$

Using the above, define next:

$$K = \frac{P_{lact}}{P_{lu}} = \frac{\epsilon_{lact}}{\epsilon_{lu}} = \frac{G_{lact}}{G_{lu}}$$

Figures 10(a)-(e), then, are plots showing how  $K$  varies with lateral position along the line  $L$ , and along the line  $\frac{1}{2}L$ . A net load of 8000 pounds was used for each figure. This load was picked arbitrarily, and similar curves would have been found for other loads, because of the similarity of the relationship between the strain curves at any load.

Area AECD is the area that would result from a uniform loading of the lap joint of Figure 3. It is 6.0 square inches for all of the graphs. This is, of course, an exact measurement. The other areas that have been noted on the figures are all approximate, because the curves were faired in using limited laboratory data.

For the 1.5 inch lap length plate, the area under the curve indicating loading along the line  $L$  is only 5.0 square inches. This would seem to indicate that even at the



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$$K = \frac{g(x)}{f(x)} = \frac{g'(x)}{f'(x)}$$

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line L, more load is being carried by the middle plate than is being carried by the two outer plates along which strains were measured. Along the line  $\frac{1}{2}L$ , the area under the curve is 4.6 inches. This shows that some of the load that was initially in the outer sheets has been transferred into the middle sheet. According to equation (8), the amount of load so transferred at the  $\frac{1}{2}L$  line would be imperceptible, but Figure 10(a) indicates that such is not the case.

The same conditions pertain for the plate with a 2 inch lap length, except that even less of the total load is acting at the bolt line (i.e., the line L).

The plate with a 3 inch lap length shows results similar to the plate with a 1.5 inch lap length. But the 2.5 and 6 inch lap length plates exhibit a peculiar phenomenon. In each of these panels there appears to be a greater load on the outer plates along the  $\frac{1}{2}L$  line than there is along the line L. The effect is most pronounced for the 6 inch lap length plate. This appears to indicate that some of the load that the pin applied to the center sheet was transmitted back to the outside sheet. This may explain the compressive forces acting at the edge of the 6 inch lap length plate, but if it does, it raises the question as to why the same transfer phenomenon does not produce compression in the



plate with a 2.5 inch lap length.

In all probability, the only safe conclusion that can be drawn from the data is that hole and pin combinations that are apparently the same, may produce variable and inconsistent results. As can be seen from Figure 7, a one inch bolt was used to apply the load at the hole. The nut was tightened with what felt like the same torque each time, but a torque wrench was not used. The holes were drilled with considerable care, but even so, it was necessary to file a portion of the edges of each hole in order to permit passage of the bolt.

If such a variation can occur while using laboratory techniques, it is even more likely that factory production methods will produce erratic results. It is believed that further investigation might well be directed at making more accurate determinations of the bearing pattern produced by a bolt or a rivet. This is not a conclusion along the lines of those that were sought when the work was initiated, but it may be that it is important, and worthy of further investigation.





## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions may be summarized from the preceding section:

- (a) Equation (8) does not hold.
- (b) It is incorrect to assume that in a pin-loaded joint, the loading is uniform along the bolt-line.
- (c) The compression of the 6 inch lap length plate can not be accounted for by the theory under investigation.
- (d) The transfer of some of the load from the inner sheets to the outer sheets can not be accounted for by the present theory.
- (e) Hole and pin combinations that are apparently the same, may produce strain patterns that vary widely and inconsistently.

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- (f) Bolt or pin bearing may not be uniform along the entire bearing surface.

It is recommended that further study be made of the pattern of bolt or pin bearing.

(1) The first of the two main parts of the book is devoted to the study of the

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TABLE I (a)

LABORATORY DATA FOR TEST SPECIMEN HAVING A 1.5 INCH LAP LENGTH.

(Numbers given are actual dial readings from strain indicator.  
f or b following gage number indicates if gage on front or  
back of plate.)

Load pounds										
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100	
1-f	10,250	10,333	10,455	10,575	10,700	10,820	10,940	11,060	11,160	
1-b	11,410	11,540	11,635	11,733	11,843	11,960	12,070	12,190	12,290	
2-f	10,890	10,980	11,110	11,228	11,340	11,450	11,560	11,658	11,735	
2-b	11,410	11,548	11,648	11,745	11,845	11,940	12,045	12,135	12,205	
3-f	This gage did not function.									
3-b	11,345	11,450	11,528	11,613	11,710	11,818	11,920	12,030	12,120	
4-f	10,528	10,620	10,650	10,670	10,688	10,700	10,720	10,750	10,770	
4-b	11,030	10,990	10,990	11,010	11,038	11,075	11,115	11,155	11,190	
5-f	10,000	10,225	10,390	10,525	10,660	10,780	10,910	11,040	11,135	
5-b	12,255	12,090	12,352	12,425	12,492	12,570	12,640	12,705	12,760	
6-f	10,868	10,900	10,930	10,952	10,980	11,000	11,025	11,050	11,070	
6-b	10,960	11,000	11,020	11,050	11,072	11,100	11,130	11,150	11,180	
7-f	10,010	10,108	10,148	10,170	10,193	10,218	10,240	10,265	10,290	
7-b	6,615	6,572	6,572	6,590	6,620	6,655	6,690	6,730	6,760	
8-f	10,700	10,810	10,875	10,921	10,965	11,005	11,048	11,083	11,110	
8-b	11,385	11,343	11,350	11,370	11,403	11,445	11,480	11,520	11,553	
9-f	9,750	9,875	9,988	10,088	10,190	10,300	10,398	10,500	10,580	
9-b	10,830	10,925	11,032	11,140	11,243	11,350	11,460	11,572	11,653	
10-f	11,450	11,770	12,053	12,315	12,600	12,878	13,150	13,428	13,650	
10-b	10,135	10,392	10,660	10,875	11,100	11,330	11,560	11,770	11,935	



TABLE I (b)

LABORATORY DATA FOR TEST SPECIMEN HAVING A 2.0 INCH LAP LENGTH.

(Numbers given are actual dial readings from strain indicator.  
f or b following gage number indicates if gage on front or  
back of plate.)

---

Load - pounds										
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Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100	
1-f	11,200	11,325	11,445	11,565	11,685	11,825	11,950	12,090	12,240	
1-b	10,925	11,040	11,142	11,250	11,360	11,470	11,590	11,730	11,860	
2-f	11,780	11,910	12,042	12,170	12,280	12,390	12,500	12,590	12,685	
2-b	11,205	11,343	11,460	11,580	11,680	11,775	11,880	11,975	12,060	
3-f	11,630	11,715	11,895	12,020	12,140	12,262	12,390	10,520	12,665	
3-b	11,663	11,765	11,870	11,980	12,100	12,210	12,332	12,470	12,605	
4-f	10,840	10,920	10,950	10,985	10,970	10,990	11,000	11,022	11,040	
4-b	10,580	10,520	10,515	10,525	10,562	10,612	10,652	10,700	10,750	
5-f	10,490	10,660	10,808	10,930	10,980	11,062	11,120	11,180	11,225	
5-b	12,445	12,390	12,360	12,350	12,403	12,470	12,510	12,630	12,720	
6-f	10,585	10,745	10,880	11,020	11,085	11,150	11,215	11,275	11,330	
6-b	10,782	10,730	10,695	10,650	10,670	10,700	10,730	10,765	10,803	
7-f	11,210	11,295	11,333	11,360	11,375	11,390	11,415	11,440	11,460	
7-b	10,340	10,280	10,265	10,270	10,305	10,340	10,375	10,420	10,465	
8-f	8,380	8,480	8,540	8,595	8,623	8,652	8,685	8,720	8,750	
8-b	10,820	10,785	10,790	10,808	10,845	10,885	10,930	10,975	11,028	
9-f	11,220	11,340	11,442	11,540	11,630	11,720	11,812	11,920	12,010	
9-b	10,105	10,240	10,385	10,525	10,640	10,750	10,868	10,980	11,110	
10-f	11,375	11,603	11,800	12,000	12,170	12,360	12,550	12,735	12,940	
10-b	11,470	11,750	12,010	12,265	12,510	12,758	13,000	13,232	13,468	

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TABLE I (c)

LABORATORY DATA FOR TEST SPECIMEN HAVING A 2.5 INCH LAP LENGTH.

(Numbers given are actual dial readings from strain indicator.  
f or b following gage number indicates if gage on front or  
back of plate.)

Load - pounds										
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100	
1-f	11,500	11,620	11,722	11,830	11,930	12,040	12,145	12,250	12,385	
1-b	11,158	11,250	11,370	11,490	11,605	11,720	11,840	11,958	12,068	
2-f	10,850	10,985	11,100	11,220	11,335	11,452	11,570	11,680	11,790	
2-b	11,050	11,142	11,258	11,372	11,490	11,610	11,730	11,845	11,952	
3-f	11,132	12,272	11,395	11,515	11,630	11,750	11,870	11,985	12,100	
3-b	10,990	11,068	11,168	11,275	11,385	11,495	11,610	11,725	11,840	
4-f	10,500	10,522	10,550	10,580	10,612	10,650	10,682	10,720	10,750	
4-b	10,630	10,660	10,690	10,720	10,750	10,775	10,803	10,830	10,858	
5-f	11,635	11,712	11,782	11,870	11,975	12,045	12,140	12,233	12,330	
5-b	12,060	12,205	12,352	12,508	12,650	12,780	12,912	13,030	13,140	
6-f	10,600	10,622	10,650	10,680	10,720	10,762	10,815	10,872	10,930	
6-b	11,642	11,740	11,830	11,925	12,015	12,095	12,778	12,250	12,315	
7-f	11,578	11,590	11,610	11,630	11,655	11,680	11,710	11,740	11,765	
7-b	11,660	11,685	11,712	11,740	11,763	11,790	11,810	11,835	11,858	
8-f	11,480	11,505	11,540	11,570	11,609	11,645	11,685	11,725	11,763	
8-b	12,240	12,285	12,325	12,368	12,405	12,430	12,480	12,512	12,550	
9-f	11,182	11,290	11,400	11,508	11,620	11,730	11,845	11,960	12,065	
9-b	12,223	12,312	12,405	12,500	12,588	12,680	12,770	12,860	12,950	
10-f	10,900	11,145	11,400	11,640	11,890	12,140	12,380	12,630	12,852	
10-b	11,800	12,000	12,205	12,408	12,600	12,805	12,990	13,185	13,345	



TABLE I (d)

LABORATORY DATA FOR TEST SPECIMEN HAVING A 3.0 INCH LAP LENGTH.

(Numbers given are actual dial readings from strain indicator.  
f or b following gage number indicates if gage on front or  
back of plate.)

---

Load - pounds										
<hr/>										
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100	
1-f	10,642	10,708	10,820	10,920	11,025	11,130	11,240	11,342	11,452	
1-b	10,915	11,040	11,050	11,250	11,378	11,470	11,585	11,688	11,802	
2-f	11,902	11,995	12,115	12,230	12,340	12,452	12,570	12,680	12,800	
2-b	11,820	11,970	12,090	12,208	12,338	12,460	12,593	12,710	12,848	
3-f	10,500	10,580	10,715	10,840	10,960	11,080	11,200	11,315	11,438	
3-b	11,528	11,658	11,752	11,840	11,940	12,042	12,148	12,250	12,362	
4-f	11,482	11,520	11,557	11,590	11,620	11,650	11,680	11,710	11,749	
4-b	11,752	11,769	11,805	11,825	11,853	11,885	11,915	11,945	11,978	
5-f	10,888	11,015	11,125	11,248	11,350	11,450	11,550	11,650	11,752	
5-b	11,390	11,462	11,575	11,660	11,760	11,870	11,982	12,080	12,188	
6-f	10,285	10,385	10,463	10,558	10,638	10,708	10,782	10,855	10,940	
6-b	10,050	10,080	10,160	10,212	10,275	10,352	10,433	10,502	10,580	
7-f	11,040	11,068	11,095	11,118	11,138	11,155	11,175	11,198	11,222	
7-b	10,730	10,738	10,762	10,775	10,795	10,820	10,843	10,862	10,890	
8-f	10,460	10,510	10,550	10,595	10,638	10,675	10,718	10,755	10,800	
8-b	10,775	10,800	10,848	10,873	10,908	10,950	10,990	11,022	11,063	
9-f	10,860	10,975	11,088	11,200	11,320	11,440	11,562	11,682	11,815	
9-b	10,580	10,685	10,800	10,905	11,015	11,122	11,235	11,342	11,458	
10-f	10,935	11,140	11,353	11,580	11,800	12,020	12,240	12,450	12,650	
10-b	13,010	13,325	13,540	13,765	13,962	14,182	14,395	14,603	14,790	

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TABLE I (e)

LABORATORY DATA FOR TEST SPECIMEN HAVING A 6.0 INCH LAP LENGTH.

(Numbers given are actual dial readings from strain indicator.  
f or b following gage number indicates if gage on front or  
back of plate.)

Load - pounds										
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100	
1-f	10,785	10,908	10,990	11,075	11,170	11,270	11,380	11,502	11,615	
1-b	11,012	11,100	11,230	11,360	11,500	11,630	11,755	11,880	12,012	
2-f	10,625	10,775	10,884	10,990	11,095	11,200	11,310	11,428	11,532	
2-b	10,370	10,490	10,625	10,760	10,890	11,015	11,138	11,248	11,372	
3-f	11,065	11,288	11,370	11,450	11,540	11,635	11,740	11,850	11,950	
3-b	11,070	11,170	11,315	11,463	11,600	11,732	11,860	11,990	12,110	
4-f	10,433	10,460	10,482	10,502	10,528	10,550	10,570	10,585	10,600	
4-b	11,640	11,653	11,660	11,670	11,680	11,690	11,710	11,730	11,745	
5-f	11,315	11,420	11,528	11,628	11,735	11,840	11,940	12,040	12,130	
5-b	10,770	10,863	10,953	11,040	11,123	11,215	11,315	11,422	11,520	
6-f	10,910	11,003	11,100	11,200	11,303	11,405	11,500	11,592	11,682	
6-b	11,730	11,829	11,920	13,010	12,098	12,192	12,290	12,400	12,500	
7-f	10,312	10,310	10,305	10,300	10,300	10,295	10,290	10,285	10,280	
7-b	10,845	10,275	10,285	10,300	10,312	10,330	10,350	10,372	10,390	
8-f	11,289	11,303	11,325	11,345	11,365	11,288	11,410	11,430	11,450	
8-b	10,260	10,275	10,285	10,300	10,312	10,330	10,350	10,372	10,390	
9-f	9,310	9,475	9,638	8,800	9,952	10,115	10,275	10,440	10,620	
9-b	11,328	11,490	11,640	11,792	11,948	12,120	12,265	12,430	12,588	
10-f	10,990	11,345	11,690	12,040	12,365	12,710	13,055	13,410	13,780	
10-b	10,715	11,050	11,350	11,648	11,940	12,242	12,540	12,830	13,120	

# TABLE 1

Summary of the results of the analysis of variance for the different factors

Source of variation: Sum of squares, D.F., Mean square, F-value, Probability > F

## TABLE 2

Factor	Sum of squares	D.F.	Mean square	F-value	Probability > F
1. Replication	1.00	1	1.00	1.00	0.32
2. Treatment	1.00	1	1.00	1.00	0.32
3. Block	1.00	1	1.00	1.00	0.32
4. Error	1.00	1	1.00	1.00	0.32
5. Total	4.00	4	1.00	1.00	0.32
6. Replication	1.00	1	1.00	1.00	0.32
7. Treatment	1.00	1	1.00	1.00	0.32
8. Block	1.00	1	1.00	1.00	0.32
9. Error	1.00	1	1.00	1.00	0.32
10. Total	4.00	4	1.00	1.00	0.32
11. Replication	1.00	1	1.00	1.00	0.32
12. Treatment	1.00	1	1.00	1.00	0.32
13. Block	1.00	1	1.00	1.00	0.32
14. Error	1.00	1	1.00	1.00	0.32
15. Total	4.00	4	1.00	1.00	0.32

TABLE II (a)

VARIATION OF STRAIN WITH APPLIED LOAD, FOR SPECIMEN HAVING  
A 1.5 INCH LAP LENGTH.

(f or b following gage number indicates if gage on front or back of plate. Ave. indicates average of front and back.)

Load - pounds									
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100
1-f	0	83	205	325	450	570	690	810	910
1-b	0	130	225	323	443	550	660	780	880
Ave.	0	107	215	324	446	560	675	795	895
2-f	0	90	220	338	450	560	670	768	845
2-b	0	138	238	335	435	530	635	725	795
Ave.	0	114	229	336	442	545	652	746	820
3-f	This gage did not function.								
3-b	0	105	183	268	365	473	575	685	775
Ave.*	0	82	173	267	370	485	591	603	795
4-f	0	92	122	142	160	172	192	222	242
4-b	0	-40	-40	-20	8	45	85	125	160
Ave.	0	26	41	61	84	108	138	174	201
5-f	0	225	390	525	660	780	910	1040	1135
5-b	0	-165	97	170	237	315	385	450	505
Ave.	0	30	243	347	448	547	647	745	820
6-f	0	32	62	84	112	132	157	182	202
6-b	0	20	40	70	92	120	150	170	200
Ave.	0	26	51	77	102	126	153	176	201
7-f	0	98	138	160	183	208	230	255	280
7-b	0	-43	-43	-25	5	40	75	115	145
Ave.	0	27	47	67	94	124	152	185	212
8-f	0	110	175	221	265	305	348	383	410
8-b	0	-42	-35	-15	18	60	95	135	168
Ave.	0	34	70	103	141	182	221	259	289
9-f	0	125	238	338	440	550	648	750	830
9-b	0	105	212	310	413	520	630	742	823
Ave.	0	115	225	324	426	535	639	746	826
10-f	0	288	603	865	1150	1438	1700	1978	2200
10-b	0	257	515	740	965	1195	1435	1635	1800
Ave.	0	288	559	802	1058	1326	1658	1806	2000

\*This average computed by assuming that, had 3-f functioned, it would have differed from 3-b by same amount as 1-f and 1-b, or 2-f and 2-b differed.

Annual Report of the Board of Directors of the  
University of California, 1917-1918

The Board of Directors of the University of California, in its annual report, presents a summary of the work of the University during the year 1917-1918. The report is divided into two parts: a general statement of the work of the University, and a detailed statement of the work of the various departments.

General Statement

Department	1917-1918	1916-1917	1915-1916	1914-1915	1913-1914	1912-1913	1911-1912	1910-1911	1909-1910	1908-1909	1907-1908	1906-1907	1905-1906	1904-1905	1903-1904	1902-1903	1901-1902	1900-1901	1899-1900	1898-1899	1897-1898	1896-1897	1895-1896	1894-1895	1893-1894	1892-1893	1891-1892	1890-1891	1889-1890	1888-1889	1887-1888	1886-1887	1885-1886	1884-1885	1883-1884	1882-1883	1881-1882	1880-1881	1879-1880	1878-1879	1877-1878	1876-1877	1875-1876	1874-1875	1873-1874	1872-1873	1871-1872	1870-1871	1869-1870	1868-1869	1867-1868	1866-1867	1865-1866	1864-1865	1863-1864	1862-1863	1861-1862	1860-1861	1859-1860	1858-1859	1857-1858	1856-1857	1855-1856	1854-1855	1853-1854	1852-1853	1851-1852	1850-1851	1849-1850	1848-1849	1847-1848	1846-1847	1845-1846	1844-1845	1843-1844	1842-1843	1841-1842	1840-1841	1839-1840	1838-1839	1837-1838	1836-1837	1835-1836	1834-1835	1833-1834	1832-1833	1831-1832	1830-1831	1829-1830	1828-1829	1827-1828	1826-1827	1825-1826	1824-1825	1823-1824	1822-1823	1821-1822	1820-1821	1819-1820	1818-1819	1817-1818	1816-1817	1815-1816	1814-1815	1813-1814	1812-1813	1811-1812	1810-1811	1809-1810	1808-1809	1807-1808	1806-1807	1805-1806	1804-1805	1803-1804	1802-1803	1801-1802	1800-1801	1799-1800	1798-1799	1797-1798	1796-1797	1795-1796	1794-1795	1793-1794	1792-1793	1791-1792	1790-1791	1789-1790	1788-1789	1787-1788	1786-1787	1785-1786	1784-1785	1783-1784	1782-1783	1781-1782	1780-1781	1779-1780	1778-1779	1777-1778	1776-1777	1775-1776	1774-1775	1773-1774	1772-1773	1771-1772	1770-1771	1769-1770	1768-1769	1767-1768	1766-1767	1765-1766	1764-1765	1763-1764	1762-1763	1761-1762	1760-1761	1759-1760	1758-1759	1757-1758	1756-1757	1755-1756	1754-1755	1753-1754	1752-1753	1751-1752	1750-1751	1749-1750	1748-1749	1747-1748	1746-1747	1745-1746	1744-1745	1743-1744	1742-1743	1741-1742	1740-1741	1739-1740	1738-1739	1737-1738	1736-1737	1735-1736	1734-1735	1733-1734	1732-1733	1731-1732	1730-1731	1729-1730	1728-1729	1727-1728	1726-1727	1725-1726	1724-1725	1723-1724	1722-1723	1721-1722	1720-1721	1719-1720	1718-1719	1717-1718	1716-1717	1715-1716	1714-1715	1713-1714	1712-1713	1711-1712	1710-1711	1709-1710	1708-1709	1707-1708	1706-1707	1705-1706	1704-1705	1703-1704	1702-1703	1701-1702	1700-1701	1699-1700	1698-1699	1697-1698	1696-1697	1695-1696	1694-1695	1693-1694	1692-1693	1691-1692	1690-1691	1689-1690	1688-1689	1687-1688	1686-1687	1685-1686	1684-1685	1683-1684	1682-1683	1681-1682	1680-1681	1679-1680	1678-1679	1677-1678	1676-1677	1675-1676	1674-1675	1673-1674	1672-1673	1671-1672	1670-1671	1669-1670	1668-1669	1667-1668	1666-1667	1665-1666	1664-1665	1663-1664	1662-1663	1661-1662	1660-1661	1659-1660	1658-1659	1657-1658	1656-1657	1655-1656	1654-1655	1653-1654	1652-1653	1651-1652	1650-1651	1649-1650	1648-1649	1647-1648	1646-1647	1645-1646	1644-1645	1643-1644	1642-1643	1641-1642	1640-1641	1639-1640	1638-1639	1637-1638	1636-1637	1635-1636	1634-1635	1633-1634	1632-1633	1631-1632	1630-1631	1629-1630	1628-1629	1627-1628	1626-1627	1625-1626	1624-1625	1623-1624	1622-1623	1621-1622	1620-1621	1619-1620	1618-1619	1617-1618	1616-1617	1615-1616	1614-1615	1613-1614	1612-1613	1611-1612	1610-1611	1609-1610	1608-1609	1607-1608	1606-1607	1605-1606	1604-1605	1603-1604	1602-1603	1601-1602	1600-1601	1599-1600	1598-1599	1597-1598	1596-1597	1595-1596	1594-1595	1593-1594	1592-1593	1591-1592	1590-1591	1589-1590	1588-1589	1587-1588	1586-1587	1585-1586	1584-1585	1583-1584	1582-1583	1581-1582	1580-1581	1579-1580	1578-1579	1577-1578	1576-1577	1575-1576	1574-1575	1573-1574	1572-1573	1571-1572	1570-1571	1569-1570	1568-1569	1567-1568	1566-1567	1565-1566	1564-1565	1563-1564	1562-1563	1561-1562	1560-1561	1559-1560	1558-1559	1557-1558	1556-1557	1555-1556	1554-1555	1553-1554	1552-1553	1551-1552	1550-1551	1549-1550	1548-1549	1547-1548	1546-1547	1545-1546	1544-1545	1543-1544	1542-1543	1541-1542	1540-1541	1539-1540	1538-1539	1537-1538	1536-1537	1535-1536	1534-1535	1533-1534	1532-1533	1531-1532	1530-1531	1529-1530	1528-1529	1527-1528	1526-1527	1525-1526	1524-1525	1523-1524	1522-1523	1521-1522	1520-1521	1519-1520	1518-1519	1517-1518	1516-1517	1515-1516	1514-1515	1513-1514	1512-1513	1511-1512	1510-1511	1509-1510	1508-1509	1507-1508	1506-1507	1505-1506	1504-1505	1503-1504	1502-1503	1501-1502	1500-1501	1499-1500	1498-1499	1497-1498	1496-1497	1495-1496	1494-1495	1493-1494	1492-1493	1491-1492	1490-1491	1489-1490	1488-1489	1487-1488	1486-1487	1485-1486	1484-1485	1483-1484	1482-1483	1481-1482	1480-1481	1479-1480	1478-1479	1477-1478	1476-1477	1475-1476	1474-1475	1473-1474	1472-1473	1471-1472	1470-1471	1469-1470	1468-1469	1467-1468	1466-1467	1465-1466	1464-1465	1463-1464	1462-1463	1461-1462	1460-1461	1459-1460	1458-1459	1457-1458	1456-1457	1455-1456	1454-1455	1453-1454	1452-1453	1451-1452	1450-1451	1449-1450	1448-1449	1447-1448	1446-1447	1445-1446	1444-1445	1443-1444	1442-1443	1441-1442	1440-1441	1439-1440	1438-1439	1437-1438	1436-1437	1435-1436	1434-1435	1433-1434	1432-1433	1431-1432	1430-1431	1429-1430	1428-1429	1427-1428	1426-1427	1425-1426	1424-1425	1423-1424	1422-1423	1421-1422	1420-1421	1419-1420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TABLE II (b)

VARIATION OF STRAIN WITH APPLIED LOAD FOR SPECIMEN HAVING  
A 2.0 INCH LAP LENGTH.

(f or b following gage number indicates if gage on front or back of plate. Ave. indicates average of front and back.)

Load - pounds									
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100
1-f	0	125	245	365	485	625	750	890	1040
1-b	0	105	217	325	435	545	665	805	935
Ave.	0	115	231	345	460	595	707	847	982
2-f	0	130	262	390	500	610	720	810	905
2-b	0	138	255	375	475	590	695	770	855
Ave.	0	134	258	382	487	600	707	790	880
3-f	0	85	265	370	490	632	760	890	1030
3-b	0	102	207	317	437	547	669	807	942
Ave.	0	93	236	344	464	589	714	849	986
4-f	0	80	110	145	130	150	160	182	200
4-b	0	-60	-65	-55	-13	32	72	120	170
Ave.	0	10	17	50	56	91	116	151	185
5-f	0	170	313	440	490	572	630	690	735
5-b	0	-55	-85	-95	-42	25	65	185	275
Ave.	0	57	116	173	224	298	347	437	515
6-f	0	160	295	435	500	565	630	690	745
6-b	0	-52	-87	-132	-112	-82	-52	-17	21
Ave.	0	54	104	151	194	241	289	336	383
7-f	0	85	123	150	165	180	205	230	250
7-b	0	-60	-75	-70	-35	0	35	80	125
Ave.	0	12	24	40	65	90	120	155	187
8-f	0	100	160	215	240	269	305	340	370
8-b	0	-35	-30	-12	25	65	110	155	208
Ave.	0	32	65	101	132	167	208	247	288
9-f	0	120	222	320	410	500	592	700	790
9-b	0	135	280	420	535	645	763	875	905
Ave.	0	128	251	370	472	573	677	787	847
10-f	0	228	425	625	795	985	1175	1360	1565
10-b	0	280	540	795	1040	1288	1530	1762	1998
Ave.	0	254	482	710	917	1136	1353	1561	1781



TABLE II (c)

VARIATION OF STRAIN WITH APPLIED LOAD FOR SPECIMEN HAVING  
A 2.5 INCH LAP LENGTH.

(f or b following gage number indicates if gage on front or back of plate. Ave. indicates average of front and back.)

Load - pounds									
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100
1-f	0	120	222	330	430	540	645	750	858
1-b	0	92	212	332	447	562	672	800	910
Ave.	0	106	217	331	438	551	658	775	884
2-f	0	135	250	370	485	602	720	830	940
2-b	0	92	208	322	450	560	680	795	902
Ave.	0	103	229	346	467	581	700	812	921
3-f	0	140	262	383	498	618	738	853	968
3-b	0	78	178	285	395	505	620	735	850
Ave.	0	119	200	334	446	562	679	794	909
4-f	0	22	50	80	112	150	182	220	250
4-b	0	30	60	90	120	145	173	200	228
Ave.	0	26	55	85	116	147	186	210	239
5-f	0	72	147	235	320	410	505	598	695
5-b	0	145	292	458	590	720	852	970	1080
Ave.	0	108	220	346	455	565	678	784	888
6-f	0	22	20	80	120	162	235	272	330
6-b	0	98	183	283	373	453	536	598	673
Ave.	0	60	108	181	246	307	375	435	501
7-f	0	12	32	52	77	102	132	162	187
7-b	0	25	52	80	103	130	150	175	198
Ave.	0	18	42	66	90	116	141	168	192
8-f	0	25	60	90	129	165	205	245	283
8-b	0	45	85	128	165	190	240	272	310
Ave.	0	35	72	108	147	177	222	259	297
9-f	0	108	218	326	436	548	663	778	883
9-b	0	89	182	277	365	457	547	637	727
Ave.	0	98	200	301	401	502	595	707	805
10-f	0	245	500	740	990	1240	1480	1730	1592
10-b	0	200	495	608	800	1005	1190	1385	1545
Ave.	0	227	452	674	895	1123	1335	1557	1748

STATE OF NEW YORK

IN SENATE

January 10, 1910.

REPORT

1909	1908	1907	1906	1905	1904	1903	1902	1901	1900	1899	1898	1897	1896	1895	1894	1893	1892	1891	1890	1889	1888	1887	1886	1885	1884	1883	1882	1881	1880	1879	1878	1877	1876	1875	1874	1873	1872	1871	1870	1869	1868	1867	1866	1865	1864	1863	1862	1861	1860	1859	1858	1857	1856	1855	1854	1853	1852	1851	1850	1849	1848	1847	1846	1845	1844	1843	1842	1841	1840	1839	1838	1837	1836	1835	1834	1833	1832	1831	1830	1829	1828	1827	1826	1825	1824	1823	1822	1821	1820	1819	1818	1817	1816	1815	1814	1813	1812	1811	1810	1809	1808	1807	1806	1805	1804	1803	1802	1801	1800	1799	1798	1797	1796	1795	1794	1793	1792	1791	1790	1789	1788	1787	1786	1785	1784	1783	1782	1781	1780	1779	1778	1777	1776	1775	1774	1773	1772	1771	1770	1769	1768	1767	1766	1765	1764	1763	1762	1761	1760	1759	1758	1757	1756	1755	1754	1753	1752	1751	1750	1749	1748	1747	1746	1745	1744	1743	1742	1741	1740	1739	1738	1737	1736	1735	1734	1733	1732	1731	1730	1729	1728	1727	1726	1725	1724	1723	1722	1721	1720	1719	1718	1717	1716	1715	1714	1713	1712	1711	1710	1709	1708	1707	1706	1705	1704	1703	1702	1701	1700	1699	1698	1697	1696	1695	1694	1693	1692	1691	1690	1689	1688	1687	1686	1685	1684	1683	1682	1681	1680	1679	1678	1677	1676	1675	1674	1673	1672	1671	1670	1669	1668	1667	1666	1665	1664	1663	1662	1661	1660	1659	1658	1657	1656	1655	1654	1653	1652	1651	1650	1649	1648	1647	1646	1645	1644	1643	1642	1641	1640	1639	1638	1637	1636	1635	1634	1633	1632	1631	1630	1629	1628	1627	1626	1625	1624	1623	1622	1621	1620	1619	1618	1617	1616	1615	1614	1613	1612	1611	1610	1609	1608	1607	1606	1605	1604	1603	1602	1601	1600	1599	1598	1597	1596	1595	1594	1593	1592	1591	1590	1589	1588	1587	1586	1585	1584	1583	1582	1581	1580	1579	1578	1577	1576	1575	1574	1573	1572	1571	1570	1569	1568	1567	1566	1565	1564	1563	1562	1561	1560	1559	1558	1557	1556	1555	1554	1553	1552	1551	1550	1549	1548	1547	1546	1545	1544	1543	1542	1541	1540	1539	1538	1537	1536	1535	1534	1533	1532	1531	1530	1529	1528	1527	1526	1525	1524	1523	1522	1521	1520	1519	1518	1517	1516	1515	1514	1513	1512	1511	1510	1509	1508	1507	1506	1505	1504	1503	1502	1501	1500	1499	1498	1497	1496	1495	1494	1493	1492	1491	1490	1489	1488	1487	1486	1485	1484	1483	1482	1481	1480	1479	1478	1477	1476	1475	1474	1473	1472	1471	1470	1469	1468	1467	1466	1465	1464	1463	1462	1461	1460	1459	1458	1457	1456	1455	1454	1453	1452	1451	1450	1449	1448	1447	1446	1445	1444	1443	1442	1441	1440	1439	1438	1437	1436	1435	1434	1433	1432	1431	1430	1429	1428	1427	1426	1425	1424	1423	1422	1421	1420	1419	1418	1417	1416	1415	1414	1413	1412	1411	1410	1409	1408	1407	1406	1405	1404	1403	1402	1401	1400	1399	1398	1397	1396	1395	1394	1393	1392	1391	1390	1389	1388	1387	1386	1385	1384	1383	1382	1381	1380	1379	1378	1377	1376	1375	1374	1373	1372	1371	1370	1369	1368	1367	1366	1365	1364	1363	1362	1361	1360	1359	1358	1357	1356	1355	1354	1353	1352	1351	1350	1349	1348	1347	1346	1345	1344	1343	1342	1341	1340	1339	1338	1337	1336	1335	1334	1333	1332	1331	1330	1329	1328	1327	1326	1325	1324	1323	1322	1321	1320	1319	1318	1317	1316	1315	1314	1313	1312	1311	1310	1309	1308	1307	1306	1305	1304	1303	1302	1301	1300	1299	1298	1297	1296	1295	1294	1293	1292	1291	1290	1289	1288	1287	1286	1285	1284	1283	1282	1281	1280	1279	1278	1277	1276	1275	1274	1273	1272	1271	1270	1269	1268	1267	1266	1265	1264	1263	1262	1261	1260	1259	1258	1257	1256	1255	1254	1253	1252	1251	1250	1249	1248	1247	1246	1245	1244	1243	1242	1241	1240	1239	1238	1237	1236	1235	1234	1233	1232	1231	1230	1229	1228	1227	1226	1225	1224	1223	1222	1221	1220	1219	1218	1217	1216	1215	1214	1213	1212	1211	1210	1209	1208	1207	1206	1205	1204	1203	1202	1201	1200	1199	1198	1197	1196	1195	1194	1193	1192	1191	1190	1189	1188	1187	1186	1185	1184	1183	1182	1181	1180	1179	1178	1177	1176	1175	1174	1173	1172	1171	1170	1169	1168	1167	1166	1165	1164	1163	1162	1161	1160	1159	1158	1157	1156	1155	1154	1153	1152	1151	1150	1149	1148	1147	1146	1145	1144	1143	1142	1141	1140	1139	1138	1137	1136	1135	1134	1133	1132	1131	1130	1129	1128	1127	1126	1125	1124	1123	1122	1121	1120	1119	1118	1117	1116	1115	1114	1113	1112	1111	1110	1109	1108	1107	1106	1105	1104	1103	1102	1101	1100	1099	1098	1097	1096	1095	1094	1093	1092	1091	1090	1089	1088	1087	1086	1085	1084	1083	1082	1081	1080	1079	1078	1077	1076	1075	1074	1073	1072	1071	1070	1069	1068	1067	1066	1065	1064	1063	1062	1061	1060	1059	1058	1057	1056	1055	1054	1053	1052	1051	1050	1049	1048	1047	1046	1045	1044	1043	1042	1041	1040	1039	1038	1037	1036	1035	1034	1033	1032	1031	1030	1029	1028	1027	1026	1025	1024	1023	1022	1021	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011	1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	1000	999	998	997	996	995	994	993	992	991	990	989	988	987	986	985	984	983	982	981	980	979	978	977	976	975	974	973	972	971	970	969	968	967	966	965	964	963	962	961	960	959	958	957	956	955	954	953	952	951	950	949	948	947	946	945	944	943	942	941	940	939	938	937	936	935	934	933	932	931	930	929	928	927	926	925	924	923	922	921	920	919	918	917	916	915	914	913	912	911	910	909	908	907	906	905	904	903	902	901	900	899	898	897	896	895	894	893	892	891	890	889	888	887	886	885	884	883	882	881	880	879	878	877	876	875	874	873	872	871	870	869	868	867	866	865	864	863	862	861	860	859	858	857	856	855	854	853	852	851	850	849	848	847	846	845	844	843	842	841	840	839	838	837	836	835	834	833	832	831	830	829	828	827	826	825	824	823	822	821	820	819	818	817	816	815	814	813	812	811	810	809	808	807	806	805	804	803	802	801	800	799	798	797	796	795	794	793	792	791	790	789	788	787	786	785	784	783	782	781	780	779	778	777	776	775	774	773	772	771	770	769	768	767	766	765	764	763	762	761	760	759	758	757	756	755	754	753	752	751	750	749	748	747	746	745	744	743	742	741	740	739	738	737	736	735	734	733	732	731	730	729	728	727	726	725	724	723	722	721	720	719	718	717	716	715	714	713	712	711	710	709	708	707	706	705	704	703	702	701	700	699	698	697	696	695	694	693	692	691	690	689	688	687	686	685	684	683	682	681	680	679	678	677	676	675	674	673	672	671	670	669	668	667	666	665	664	663	662	661	660	659	658	657	656	655	654	653	652	651	650	649	648	647	646	645	644	643	642	641	640	639	638	637	636	635	634	633	632	631	630	629	628	627	626	625	624	623	622	621	620	619	618	617	616	615	614	613	612	611	610	609	608	607	606	605	604	603	602	601	600	599	598	597	596	595	594	593	592	591	590	589	588	587	586	585	584	583	582	581	580	579	578	577	576	575	574	573	572	571	570	569	568	567	566	565	564	563	562	561	560	559	558	557	556	555	554	553	552	551	550	549	548	547	546	545	544	543	542	541	540	539	538	537	536	535	534	533	532	531	530	529	528	527	526	525	524	523	522	521	520	519	518	517	516	515	514	513	512	511	510	509	508	507	506
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TABLE II (d)

VARIATION OF STRAIN WITH APPLIED LOAD FOR SPECIMEN HAVING  
A 3.0 INCH LAP LENGTH.

(f or b following gage number indicates if gage on front or back of plate. Ave. indicates average of front and back.)

Load - pounds									
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100
1-f	0	66	178	278	383	482	598	700	810
1-b	0	125	135	335	463	555	670	773	887
Ave.	0	96	156	336	423	521	634	736	848
2-f	0	93	213	328	438	550	662	778	898
2-b	0	150	270	388	578	640	773	890	1028
Ave.	0	121	241	358	478	595	717	834	963
3-f	0	80	215	340	460	580	700	815	938
3-b	0	140	224	312	412	514	620	722	834
Ave.	0	110	219	326	435	547	660	775	886
4-f	0	38	75	108	138	168	198	228	267
4-b	0	17	53	73	101	133	163	193	226
Ave.	0	27	64	90	119	150	180	210	241
5-f	0	127	237	360	462	562	662	762	864
5-b	0	72	185	270	370	480	592	690	798
Ave.	0	99	211	315	416	521	627	726	831
6-f	0	100	178	273	353	423	497	570	655
6-b	0	30	110	162	225	302	383	452	530
Ave.	0	65	144	217	289	362	440	511	592
7-f	0	28	55	78	98	115	135	158	182
7-b	0	8	32	45	65	90	113	132	160
Ave.	0	18	43	61	81	102	124	145	171
8-f	0	50	90	135	178	215	258	295	330
8-b	0	25	73	98	133	175	215	247	288
Ave.	0	37	82	116	155	195	236	271	309
9-f	0	115	228	340	460	580	702	822	955
9-b	0	105	220	325	435	542	655	762	878
Ave.	0	110	224	332	447	559	679	792	917
10-f	0	205	418	645	865	1075	1295	1515	1715
10-b	0	315	530	755	952	1172	1385	1593	1780
Ave.	0	260	474	700	908	1124	1340	1554	1747



TABLE II (e)

VARIATION OF STRAIN WITH APPLIED LOAD FOR SPECIMEN HAVING  
A 6.0 INCH LAP LENGTH.

(f or b following gage number indicates if gage on front or back of plate. Ave. indicates average of front and back.)

Load - pounds									
Gage	100	1,100	2,100	3,100	4,100	5,100	6,100	7,100	8,100
1-f	0	123	205	290	385	485	595	717	830
1-b	0	88	218	348	488	618	743	868	1000
Ave.	0	105	211	319	436	551	669	792	915
2-f	0	150	259	365	470	575	685	803	908
2-b	0	120	255	390	520	645	768	878	1002
Ave.	0	135	257	377	495	617	726	840	955
3-f	0	223	305	385	475	570	675	785	885
3-b	0	100	245	393	530	662	790	920	1040
Ave.	0	161	275	389	502	606	732	852	962
4-f	0	27	49	69	95	117	137	152	167
4-b	0	13	20	30	40	50	70	90	105
Ave.	0	20	35	50	67	83	103	121	136
5-f	0	105	213	313	420	525	625	725	815
5-b	0	93	183	270	353	445	545	652	750
Ave.	0	99	198	291	386	495	595	688	783
6-f	0	93	190	290	393	495	590	682	772
6-b	0	99	190	280	365	462	560	670	770
Ave.	0	96	190	285	379	478	575	676	771
7-f*	0	-2	-7	-12	-12	-17	-22	-27	-32
7-b*	0	-5	-15	-25	-35	-43	-45	-45	-55
Ave.	0	-3	-11	-18	-24	-30	-34	-36	-44
8-f	0	14	36	56	76	99	121	141	161
8-b	0	15	25	40	52	70	90	112	130
Ave.	0	14	30	44	64	85	105	127	145
9-f	0	165	328	490	642	805	965	1130	1310
9-b	0	162	312	464	620	792	937	1102	1260
Ave.	0	163	320	477	631	798	951	1116	1285
10-f	0	355	700	1050	1375	1720	2065	2420	2790
10-b	0	335	635	932	1225	1527	1825	2115	2405
Ave.	0	345	667	966	1300	1623	1945	2267	2598

\*Readings for 7-f and 7-b were checked with two Huggenberger  
 Tensometers in a line with gages 7-10, but  $11\frac{1}{2}$  inches from  
 gages 7-f and 7-b.





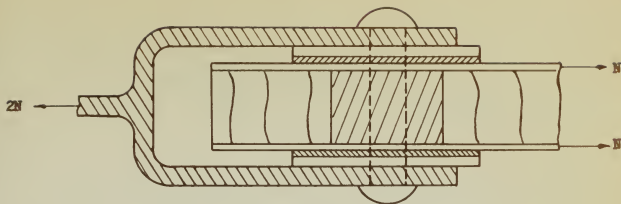


Figure 1 - One type of sandwich fitting.

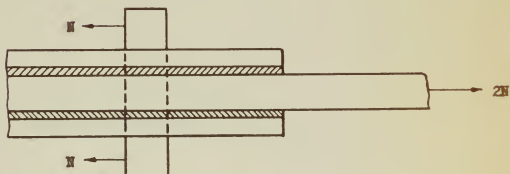
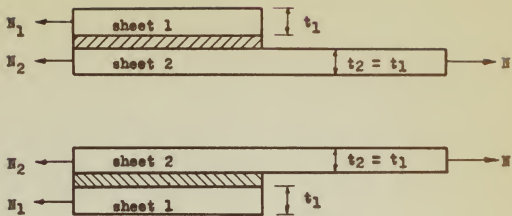
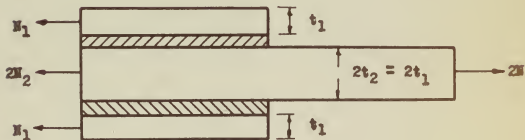


Figure 2 - Test specimen.





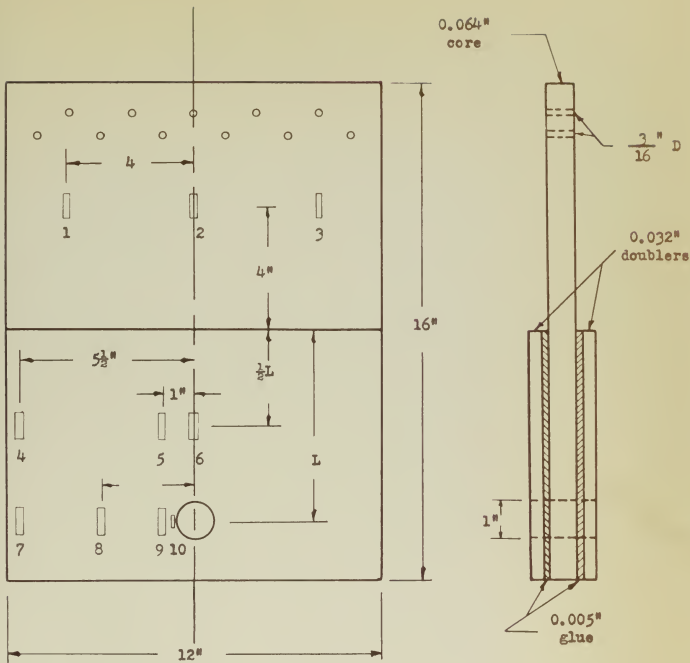
(a) Case for which theory was developed.



(b) Actual test specimen

Figure 3 - Two types of lap joint.





(a) Front view, showing location and numbering of strain gages.

(b) Side view.

Figure 4 - Test specimen.





Figure 5 - Test specimen of three inch lap length. Shown are nine A-11 strain gages and one A-8.

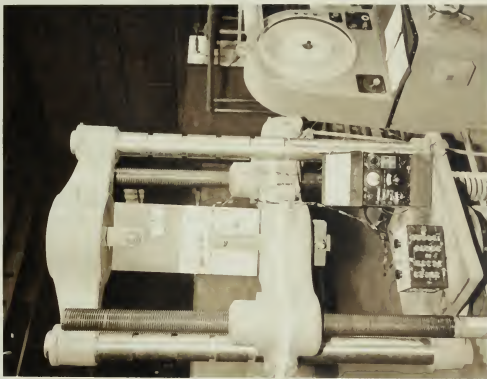


Figure 6 - Specimen mounted in testing machine, showing load indicator dial, switch box, and strain indicator.





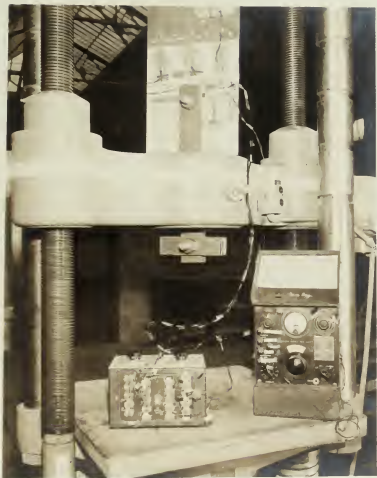


Figure 7 - Specimen mounted in testing machine. Close-up, showing tee-section used in place of standard grips.



Figure 8(a) - Plot of measured strain vs.  
location for constant loads.

$L = 1.5$  inches

Strains measured along line  
of distance  $L$  from edge of  
doubler.

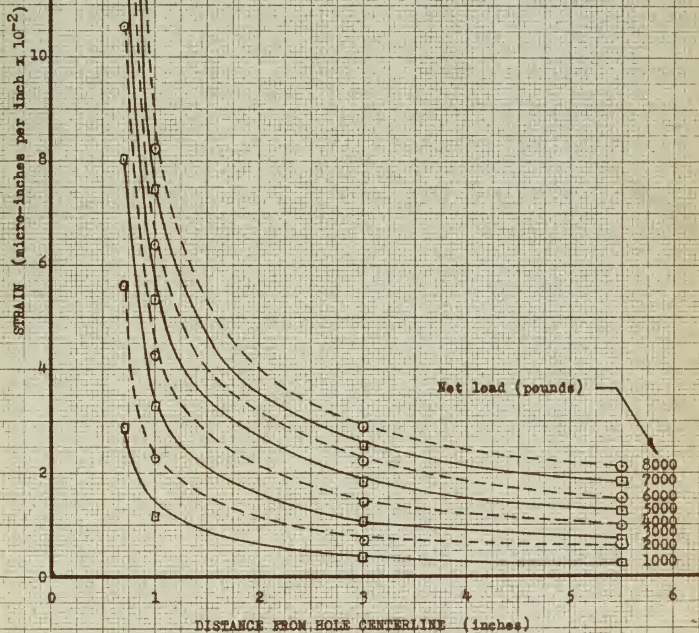




Figure 8(b) - Plot of measured strain vs. location for constant loads.

$L = 2$  inches

Strains measured along line of distance  $L$  from edge of doubler.

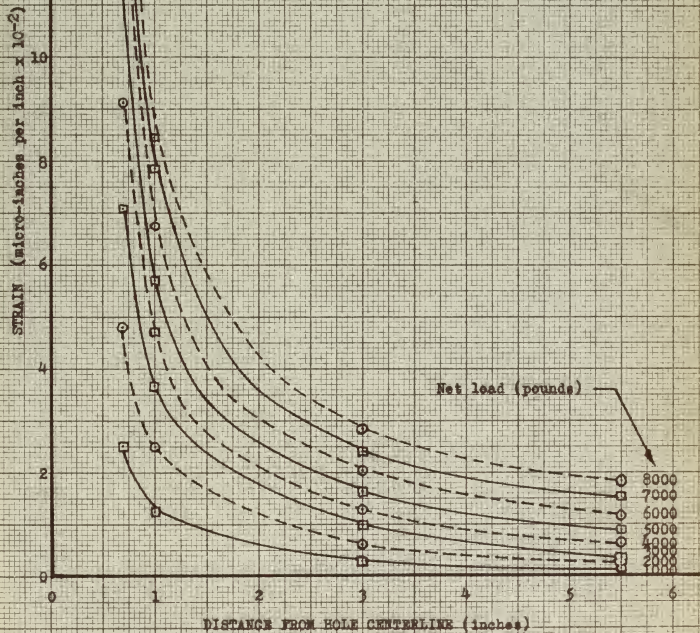






Figure 8(c) - Plot of measured strain vs. location for constant loads.

$L = 2.5$  inches

Strains measured along line of distance  $L$  from edge of doubler.

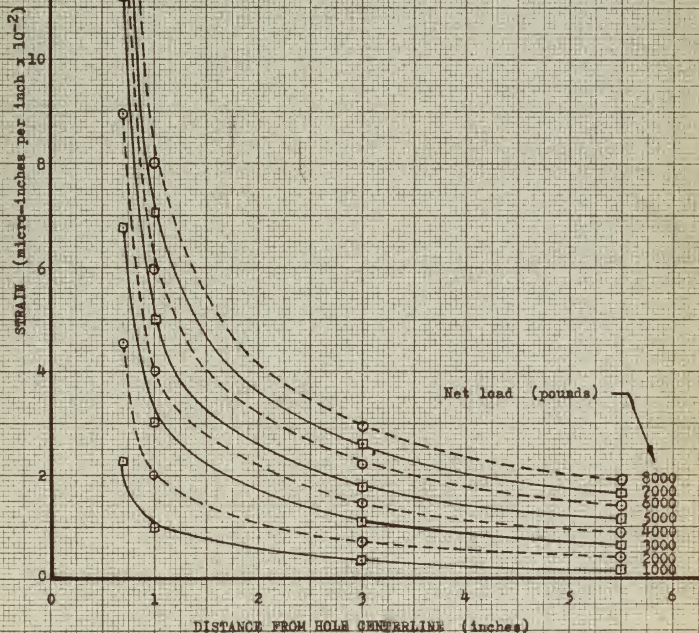






Figure 8(d) - Plot of measured strain vs. location for constant loads.

$L = 3$  inches

Strains measured along line of distance  $L$  from edge of doubler.

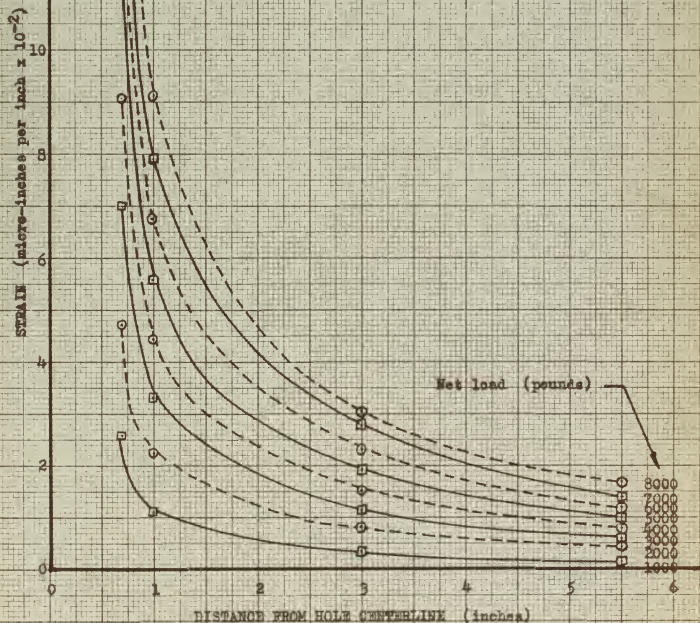




Figure 8(e) - Plot of measured strain vs. location for constant loads.

L = 6 inches

Strains measured along line of distance L from edge of doubler.

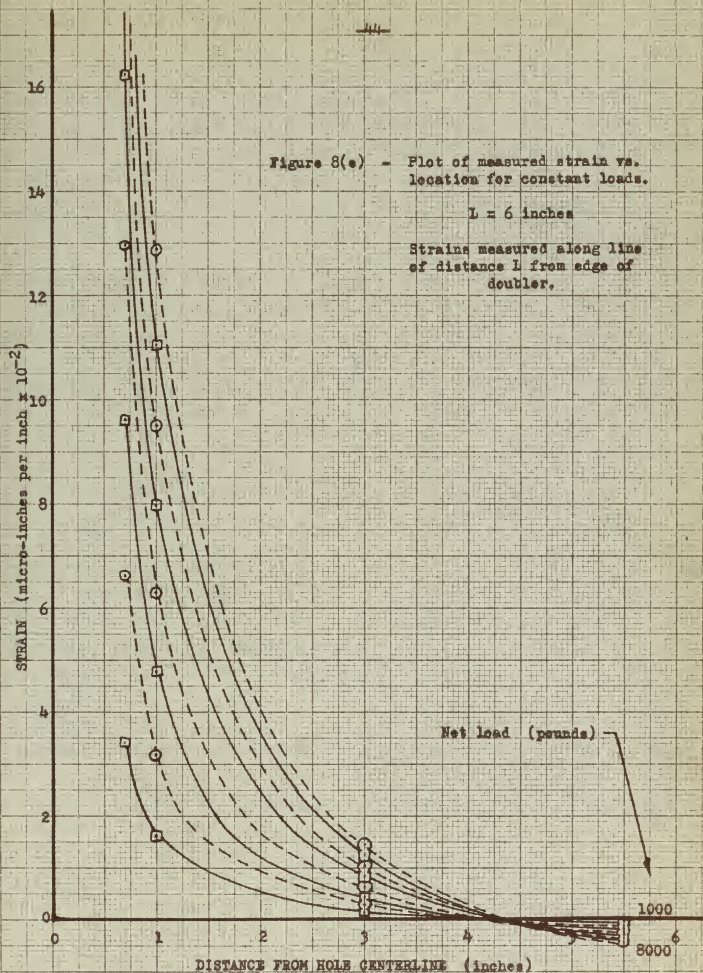
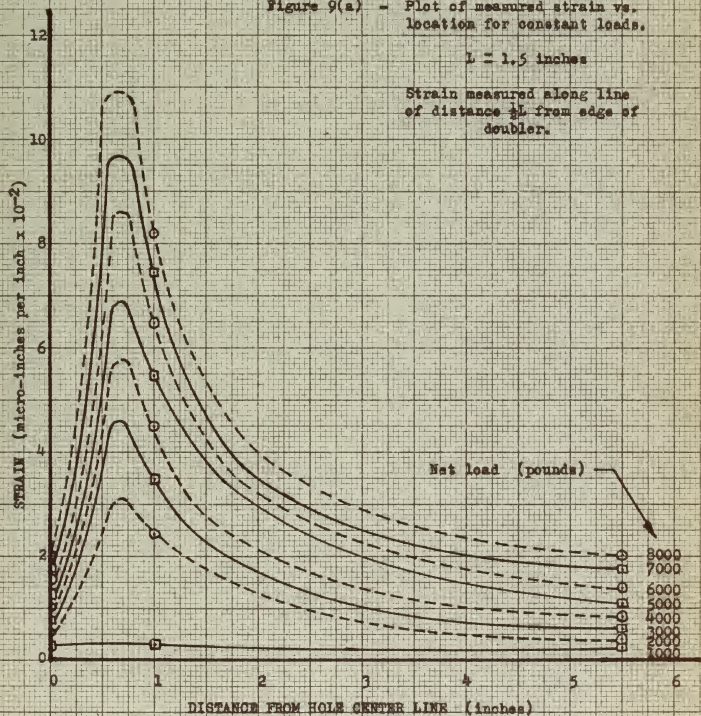




Figure 9(a) - Plot of measured strain vs. location for constant loads.

$L = 1.5$  inches

Strain measured along line of distance  $\frac{1}{2}L$  from edge of doubler.





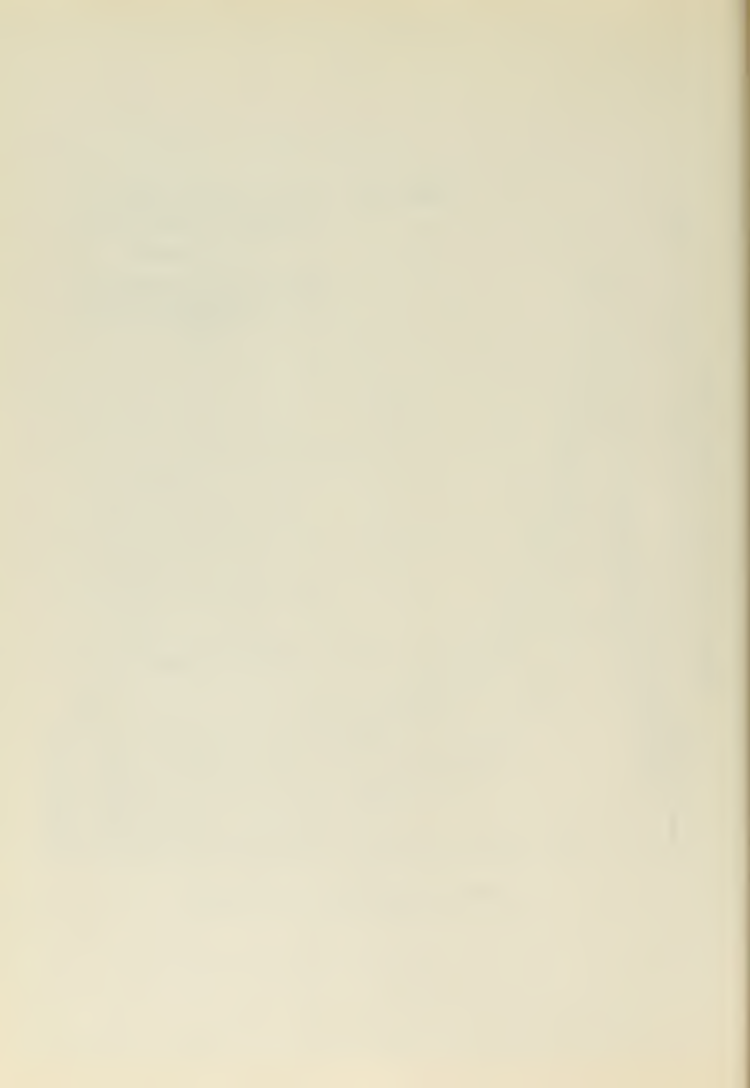


Figure 9(b) - Plot of measured strain vs. location for constant loads.

$L = 2$  inches

Strains measured along line of distance  $2L$  from edge of doubler.

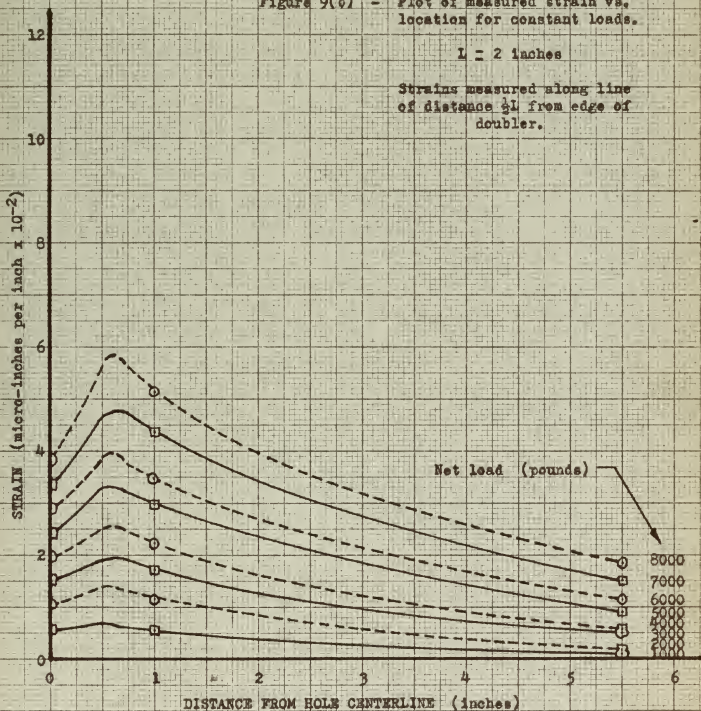






Figure 9(c) - Plot of measured strain vs. location for constant loads.

$L = 2.5$  inches

Strain measured along line of distance  $\frac{1}{2}L$  from edge of doubler.

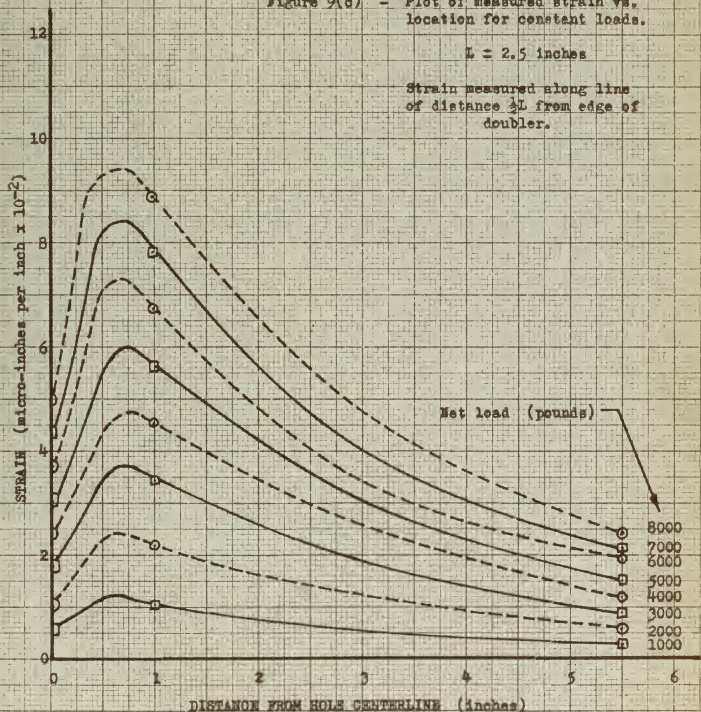




Figure 9(d) - Plot of measured strain vs. location for constant loads.

$L = 3$  inches

Strains measured along line of distance  $\frac{1}{2}L$  from edge of doubler.

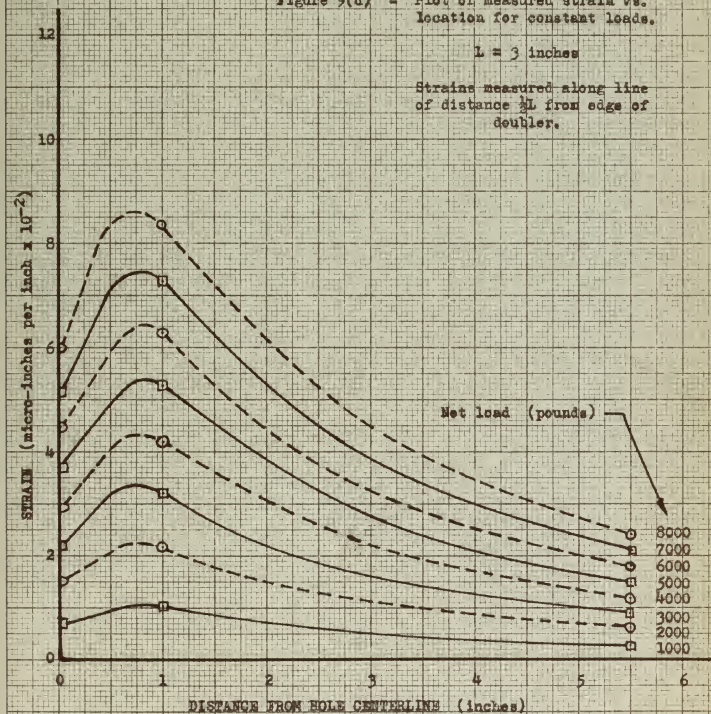
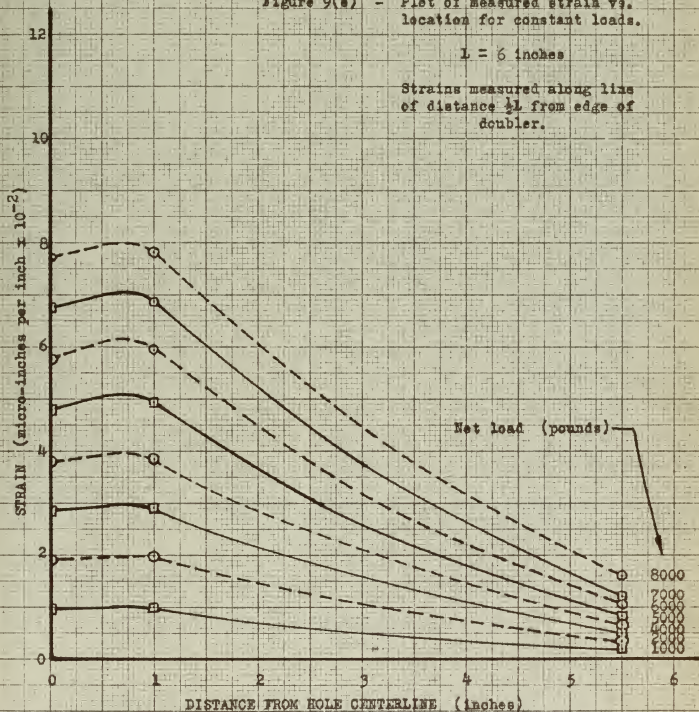




Figure 9(a) - Plot of measured strain vs. location for constant loads.

$L = 6$  inches

Strains measured along line of distance  $\frac{1}{2}L$  from edge of doubler.







Area ABCD - 6.0 square inches

2 x Area EFGHI - 5.0 square inches

Area HFKJLMD - 4.6 square inches

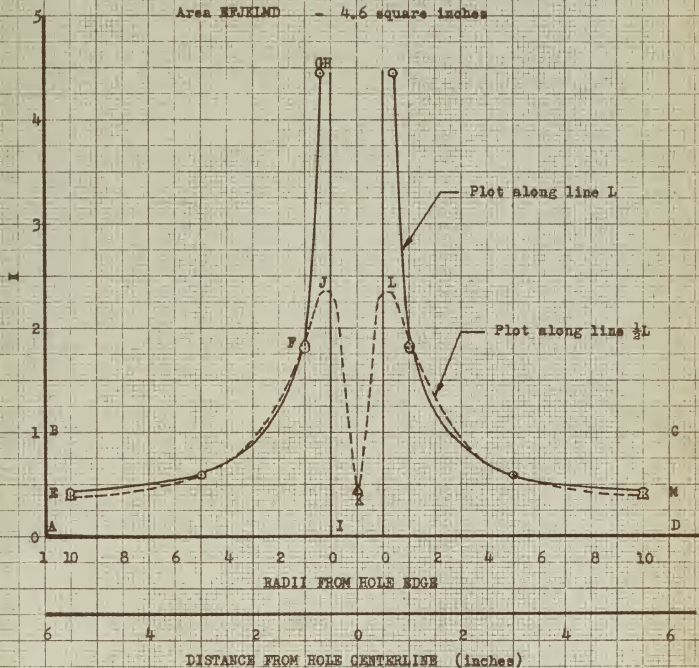


Figure 10(a) - Plot showing the effect of lateral location on the ratio of actual  $p_1$  to theoretical  $p_1$ . Plots made along line L and along line  $\frac{1}{2}L$ .  
8000 pounds net load.  
 $L = 1.5$  inches.





Area ABCD - 6.0 square inches  
 2 x Area EFGHI - 5.1 square inches  
 Area HFKLMD - 3.5 square inches

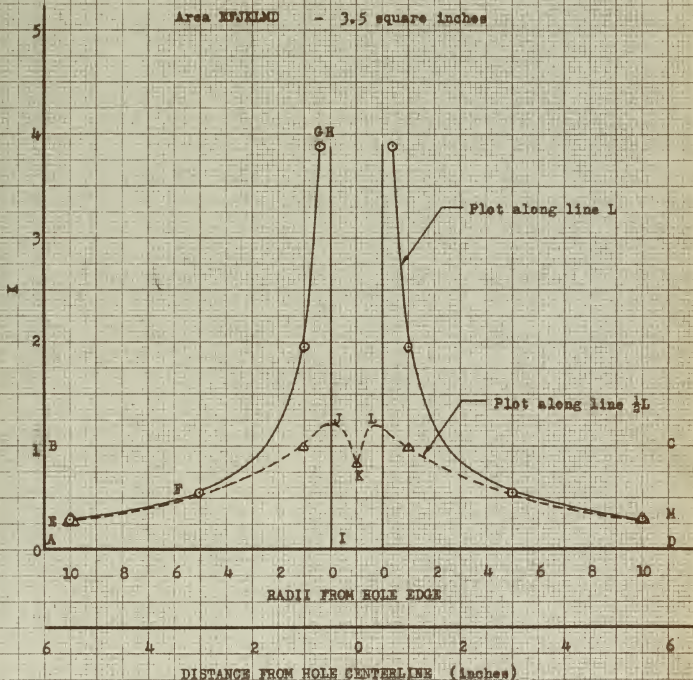


Figure 10(b) - Plot showing the effect of lateral location on the ratio of actual  $p_1$  to theoretical  $p_1$ . Plots made along line L and along line  $\frac{1}{2}L$ .  
 8000 pounds net load.  
 $L = 2$  inches.



Area ABCD - 6.0 square inches  
 2 x Area EFGHI - 4.9 square inches  
 Area EFJLMD - 5.6 square inches

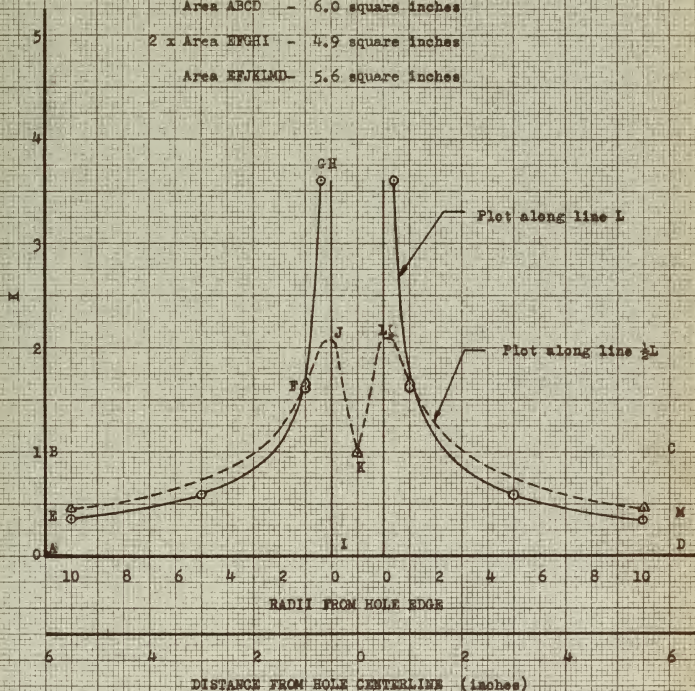


Figure 10(c) - Plot showing the effect of lateral location on the ratio of actual  $p_1$  to theoretical  $p_1$ . Plots made along line L and along line  $\frac{1}{2}L$ .  
 3000 pounds net load.  
 $L = 2.5$  inches.



Area ABCD = 6.0 square inches

2 x Area EFGHI = 5.6 square inches

Area EFJELMD = 5.5 square inches

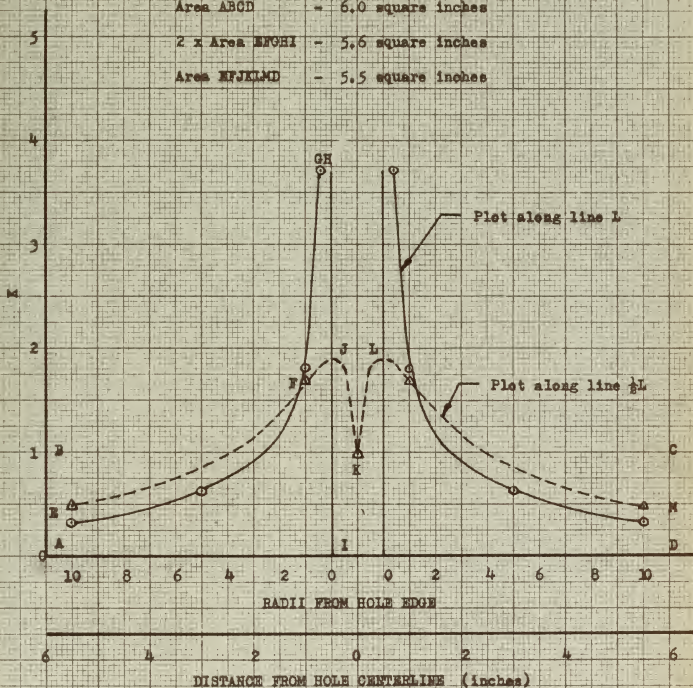
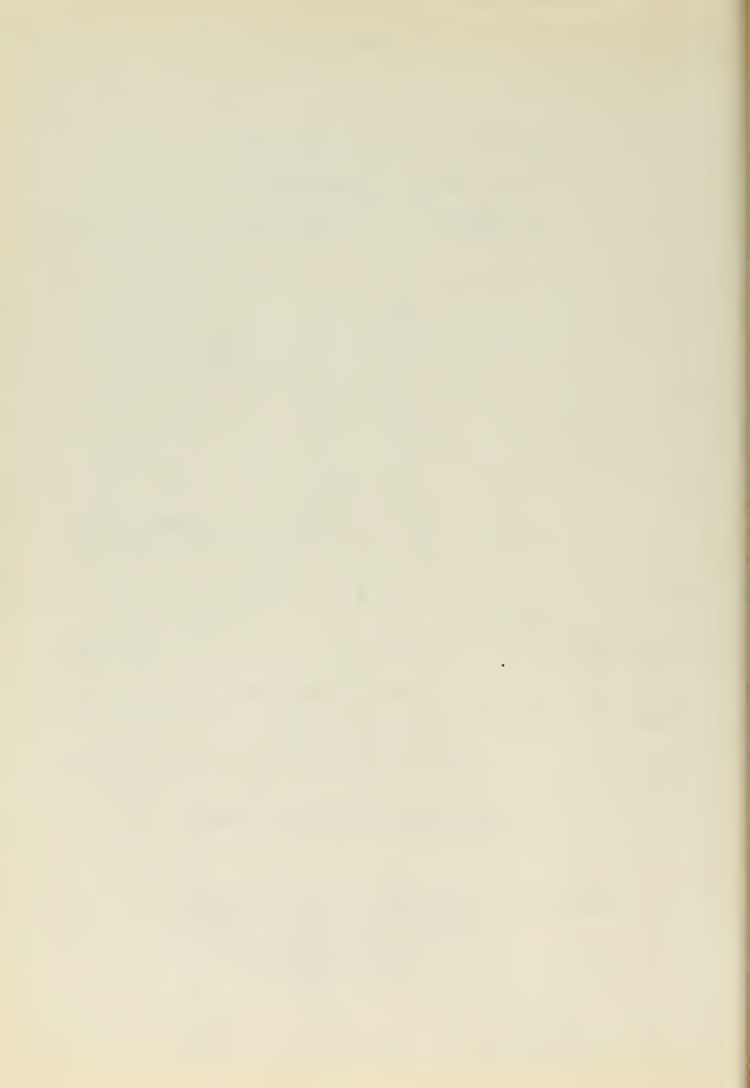


Figure 10(d) - Plot showing the effect of lateral location on the ratio of actual  $p_1$  to theoretical  $p_1$ . Plots made along line L and along line  $\frac{1}{2}L$ .  
8000 pounds net load.  
 $L = 3$  inches.





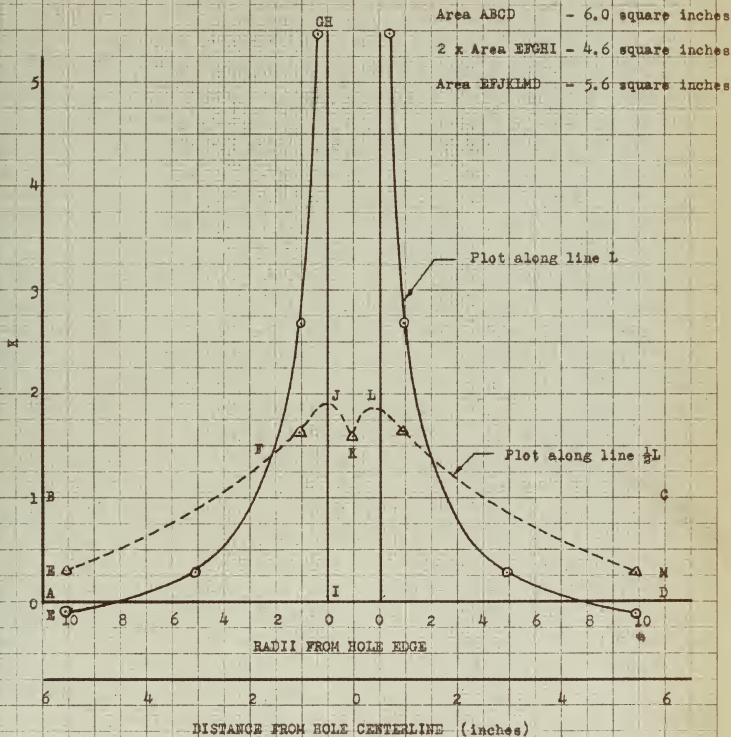
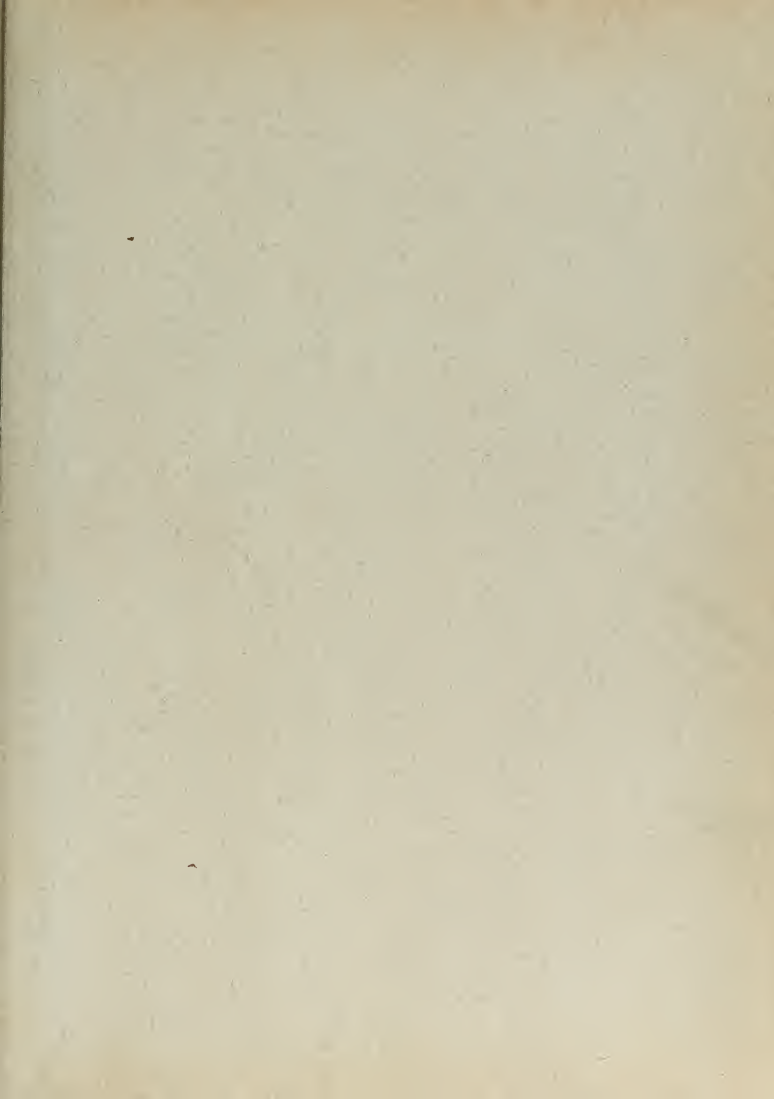


Figure 10(e) - Plot showing the effect of lateral location on the ratio of actual  $p_1$  to theoretical  $p_1$ . Plots made along line L and along line  $\frac{1}{2}L$ .  
 8000 pounds net load.  
 $L = 6$  inches.







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